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Strategic flexibility analysis of agrifood nanotechnology skill needs identification

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A B S T R A C T

The world is experiencing significant, largely economic and sociotechnical, induced change. These induced changes are meaningful with a function of people taking collective actions around common beliefs. These changes are more than jargon, cliché, and hyperbole, and they are effecting major transformations. These transformations will impact on how human resources are developed, and we need to be able to forecast its effects. In order to produce such forecasts, Human Resource Development needs to become more predictive - to develop the ability to understand how human capital systems and organizations will behave in future. As part of a multi-phase, mixed methods study design based on systems and complexity theories to identify skill needs for the emerging agrifood nanotechnology sector, a strategic flexibility analysis (SFA) was conducted. Strategic Flexibility Framework (SFF) is a scenario analysis tool and its use in this study is based on the idea that Business Leaders, Managers, Educators and Human Resource Development professionals require flexibility to adjust decisions within given constraints. This paper describes the use of strategic flexibility analysis and the qualitative systems approaches as tools for systems research and it implications for human resources development and management.

1. Background of study

The world is experiencing significant, largely economic and sociotechnical, induced change. These induced changes are meaningful with a function of people taking collective actions around common beliefs. These changes are more than jargon, cliché and hyperbole, and they are effecting major transformations. These transformations however, should consistently meet the growth expectations of various constituents in an increasingly competitive global marketplace through a kind of leadership that solves complex social, economic, and political problems by leveraging the opportunities of an interconnected world (Holliday, 2013; Scheinfeldt, 2012).

These game changing developments have the dimensions of space and time. An action of a group of people or individual can have a game changing impact in just a particular locality or region; or can have global impact (Yawson, 2015). These transformations will impact on how human resources are developed and we need to be able to forecast its effects. In order to produce such forecasts, Human Resource Development (HRD) needs to become more predictive - to develop the ability to understand how human capital systems and organizations will behave in future.

Further development of systems models is required to allow such predictions to be made. Critical to the development of such models will be to understand that linear epistemology cannot be the dominant epistemology of practice and that dynamic complexity of challenges confronted by HRD professionals in their daily research and practice requires a nonlinear epistemology of practice, rather than reductive or linear thinking or processes of normal science (Yawson, 2013). Central to this will be the use of systems approach in HRD research. A systems approach in which physiognomies of one level in a hierarchy are reconnoitered as emergent properties of processes lower down in the hierarchy (Norris, 2012), will be important for making HRD predictions in novel conditions. The reason for this is that systems approaches do not assume that the validity of a systems description is interminable (as do phenomenological models by definition), "they rely on the fact that the internal processes will continue to operate into the future and that their operation will be in some way altered by the changed conditions" (Evans et al., 2012, p. 164). The higher order emergent properties change as a consequence of the shifts in the internal processes not because the higher order effects themselves have been projected into the future (Evans et al., 2012).

Although the adoption of a systems approach to research in HRD is not novel, methodologies and concepts underlying the approach are not very well developed. In a mixed methods study to identify skill needs for agrifood nanotechnology, a comprehensive methodology was developed for a systems approach research in agricultural education, public policy and HRD. In this paper, scenario planning analysis methodology that was developed as part of a novel method in conducting systems approach research in human resource development is described.

This study was part of a multi-phase, mixed methods study design (Creswell & Plano-Clark, 2011) based on systems theory and complexity

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theory. The main study was an interdisciplinary study involving disparate fields of systems theory; nanoscience and nanotechnology; science policy; agricultural education; human resource development and workforce education. The research was based on theory that accounted for the dynamic aspects of systems modeling, complexity theory, skill identification and workforce development. This interdisciplinary approach was predicated on the conception that "disciplinarity is no longer the dominant system for creating and organizing knowledge, and that knowledge creation is now trans-disciplinary, more reflexive, non-linear, complex and hybridized" (Yawson, 2009, p. 9). Lubet (2009) in discussing his pioneering role in the field of Disability Studies in Music described this scholarly approach as the tenets of "epistemology of interdisciplinarity" (p. 120).

The main multiphase study followed a four-step process involving different methods and approaches. The first phase marked (1) in the schematic diagram in Fig. 1 involved a comprehensive systematic evidence review (SER) and analysis of the literature. This phase of the study was also used to identify key experts, conduct stakeholder analysis, and formulate questions for in-depth and semi-structured interviews. The second phase of the study, marked [2] in the schematic diagram used multi-criteria approaches for value elicitation including surveys and semi-structured interviews with key stakeholders and experts to identify current and future skill needs in agrifood nanotechnology sector. The third phase of the study (marked [3] in the schematic diagram) included Qualitative Systems Analysis (QSA); Quantitative Data Analysis (QDA); and Strategic Flexibility Analysis (SFA) (a scenario analysis method) of evidence from the literature and results from the multi-criteria value elicitation of experts and stakeholders. The final phase of the study (marked [4] in the schematic diagram) created a systems model from the QDA, QSA and SFA to describe holistically the current and future skill needs and the important links, interrelationships and apparent themes and patterns identified in the prior phases. This paper describes the use of Strategic Flexibility Analysis as a Tool for Systems Research and it implications for management practice.

2. Strategic flexibility framework: a scenario analysis tool

The Strategic Flexibility Framework (SFF) is a scenario analysis tool and its use in this study is based on the idea that Business Leaders, Managers, Educators and Human Resource Development professionals require flexibility to adjust decisions within given constraints. Various definitions of 'scenarios' can be found in the literature. Bradfield et al. (2005:796) have contended that "there appears to be virtually no area in scenarios on which there is wide-spread consensus; the literature reveals a large number of different and at times conflicting definitions, characteristics, principles and methodological ideas about scenarios"

There is however, a broad agreement that all the definitions converge, in that, scenarios are not forecasts or predictions of future developments, but rather descriptions of how the future might unfold, mapping out the 'possibility space' of future developments (Bradfield et al., 2005; Giaoutzi et al., 2011; Zanoli et al., 2012). Zanoli et al. (2012) defined scenario analysis as a tool for strategic policy analysis that allows researchers and policymakers to support decision making, and a systemic analysis of the main determinants of an organization, sector or policy issue. Scenario analyses are powerful tools in modern policy analysis, in both the private and the public domains (Giaoutzi et al., 2011).

Scenario analyses are very different from other forecasting methods in that they usually provide a more qualitative and contextual description of how the present will evolve into the future, rather than a description that seeks numerical precision (Bradfield, 2008; Zanoli et al., 2012). Another important difference is that, they are generally used to identify a set of possible futures, where there is the possibility of occurrence, but without any certainty (Zanoli et al., 2012). Therefore, one will have to understand that "scenario analysis is a process of understanding, analyzing and describing the behaviors of complex systems in a consistent and, as far as possible, complete way" (Zanoli et al., 2012:42). Wack (1985:150) defined scenario analysis as: "a discipline for rediscovering the original entrepreneurial power of creative foresight in context of accelerated change, greater complexity and genuine uncertainty".

Although scenario techniques have a long history dating back in time immemorial, the modern day scenario techniques, only emerged in the post-war period and was originally developed for strategic military purposes (Bradfield, 2008; Bradfield et al., 2005; Zanoli et al., 2012). From the work of Herman Kahn and others at RAND and the Hudson Institute in the 1960s, scenarios reached a new dimension with the work of Pierre Wack in Royal Dutch/Shell (Saritas and Nugroho, 2012). Since then numerous models have been published, with the first journal article on comprehensive model for the development of scenarios published by Zentner in 1975 (Bradfield, 2008). The literature is now replete with descriptions of prototypical patterns or models for generating scenarios ranging from the simple to the elaborate and highly structured recipe-type techniques (Bradfield, 2008).

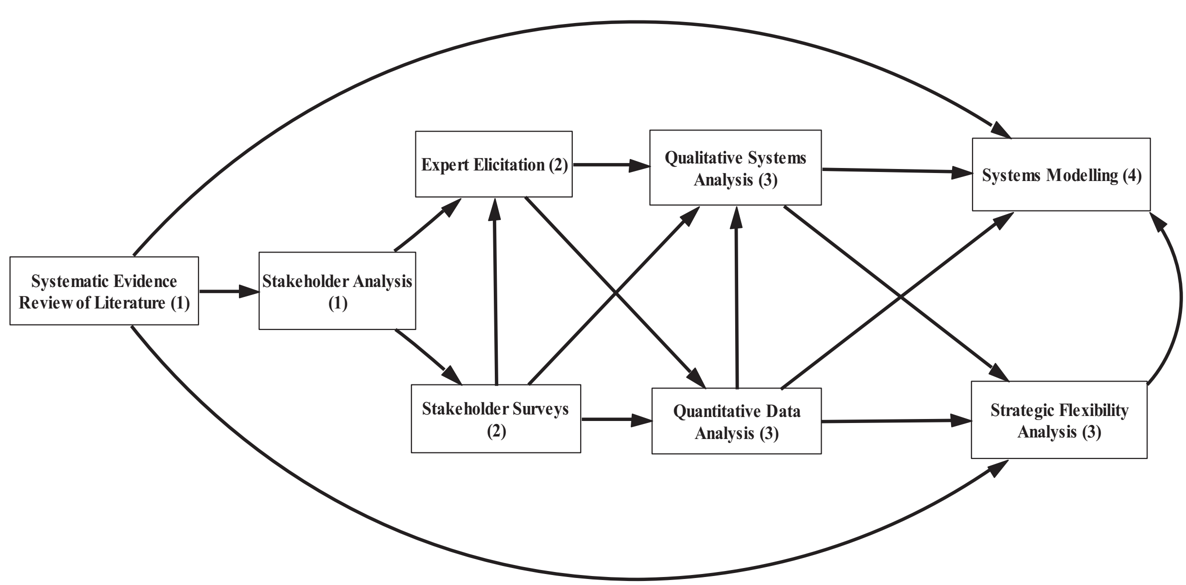

Fig. 1. Schematic representation of research framework.

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Scenarios can be categorized into exploratory/forecasting and normative/inward/backcasting. Exploratory scenarios begin with the analysis of the present and link to the future by asking questions such as "What next?" and "What if?" (Saritas and Nugroho, 2012; Zanoli et al., 2012). Normative, or inward scenarios, involve backcasting, where the focus is not on what futures are likely to happen, but starting with the most desirable future (Giaoutzi et al., 2011). Typical questions for normative scenarios are "Where to?" and How to?" (Saritas and Nugroho, 2012). Scenario analysis can also be classified into quantitative and qualitative scenarios. While quantitative scenarios are often model based, qualitative scenarios describe possible futures in the form of narrative texts or "story lines" (Zanoli et al., 2012). Another important classification of scenarios based on the approach used is categorized into participatory/expert-based scenarios, and desk-analysis scenarios. Participatory scenarios are approaches where experts and stakeholders play active roles in the scenario-generation system (Zanoli et al., 2012). Desk analysis scenarios exploit information based on the existing literature and/or statistical data, which is then elaborated in a scenario form without a collaborative process (Zanoli et al., 2012).

The basic aim of scenario analysis is not forecasting the future, or fully characterizing its uncertainty, but rather bounding this uncertainty (Zanoli et al., 2012). Scenario analyses help focus attention to driving forces, possibilities of evolution, and the extent of contingencies that may be confronted (Saritas and Nugroho, 2012). They are particularly useful when many factors need to be considered, and the degree of uncertainty about the future is high (Saritas and Nugroho, 2012). "With respect to nanotechnology, scenario planning may serve as a useful technique for scientists and engineers to engage with social scientists, humanists and policymakers in better understanding and reflecting about nanotechnology in society" (Farber and Lakhtakia, 2009: S5).

Strategic uncertainty that is associated with identification of future skill needs for emerging agrifood nanotechnology requires strategic flexibility, the ability to change strategies (Malik et al., 2009a,b). Human Resources Development and Management professionals in the agrifood system risk arbitrarily narrowing their options of meeting the challenge of developing the human resources equipped with the requisite agrifood nanoskills if they attempt to base how the workforce should be developed on a precisely predicted skill requirements alone. This could prevent the consideration of a broader range of future possibilities. Human Resources Development and Management professionals need a range of future possibilities and corresponding strategy choices in tailoring their activities, rather than one strategy based on a declared vision of certain future skill requirements (Malik et al., 2009a,b). The 'known unknowns' are also very important.

As shown in Fig. 2, SFA is a four-step framework, defined by Michael Raynor in his book *The Strategy Paradox*: *Why Committing to Success Leads to Failure (and what to do about it)*. The implementation steps are Anticipation, Accumulation, Formulation, and Operation. Fig. 2 is a pictorial representation of the framework adapted from Raynor (2007). The following description of the steps is drawn heavily from Malik et al. (2009a) *focus on the future of food* report.

Anticipate – The process begins by defining the drivers that are shaping the agrifood nanoskill needs of the future. Once these drivers are understood, the next step is to develop scenarios that provide "stories" about possible future realities (Malik et al., 2009a,b). These scenarios are statements of how the nanotechnology could shape the entire agrifood system and the logical consequence for new skills requirements.

Formulate - For any given scenario, this step determines the strategies for success under different conditions. Each scenario has an optimal strategy. Each optimal strategy consists of various constituent elements — technologies, capabilities, and assets — required to execute the strategy. Elements common to many optimal strategies (one derived from each scenario) are core elements; those common to a few or one optimal strategy are called contingent elements.

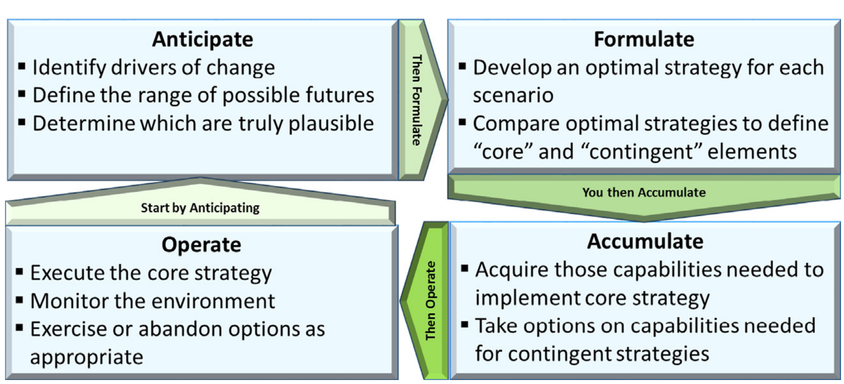
Accumulate - Core elements have little strategic risk because they are part of the optimal strategies for multiple scenarios. Contingent elements require an options-based approach, which gives choices for allocating resources. In the accumulation phase, the decision maker commits to core elements and takes options on contingent elements.

Operate - This step involves monitoring the environment to determine which scenario accurately captures the most important elements of the future. This involves choosing the most appropriate optimal strategy, determining the necessary contingent elements, and deciding which options to exercise or abandon. The set of scenarios must be reviewed and, if needed, refreshed, or redeveloped.

3. Overview of the methods and data collection measures of the main study

Different methods and approaches were used in collecting data for the main study. The methods and data collection measures were designed to answer the research questions the study set out to address. The main research question guiding the study was: ***What are the future skill needs in agrifood nanotechnology?*** The study also addressed the following related questions:

1. Who are the key stakeholders in agrifood nanotechnology workforce development and how do they perceive skills shortages and gaps in the sector?



Note: Re-drawn from Raynor (2007)

Fig. 2. The four phases of strategic flexibility.
Note: Re-drawn from Raynor (2007).

2. Based on an understanding of skill shortages and gaps, how can educational practice and policy meet these needs?
3. What policies and programmatic intervention points can serve as leverage points for increasing the likelihood of preventing skill gaps and shortages in the agrifood sector?

The research methodology designed to answer these questions is as described earlier is follows: First, a systematic evidence review of the literature was done to answer the main research question. A stakeholder analysis was conducted to identify the stakeholders directly affected and responsible for skill needs in agrifood nanotechnology and also to select the stakeholders from whom data will be collected. A Multicriteria Value Elicitation of quantitative and qualitative evidence was then collected from the identified experts and stakeholders. The study used mixed methods sampling strategy combining the concurrent and sequential collection of quantitative and qualitative data (Creswell & Plano-Clark, 2011; Teddlie & Yu, 2007). The sample sizes of stakeholders and experts surveyed and interviewed varied. Overall a total of 225 participants, including individuals (experts and individual stakeholders) and representatives of stakeholder groups: Educational institutions, industry/business, and government organizations responded to the various elicitation protocols.

The analysis phase of the main study included the analysis of the Systematic Evidence Review (SER), qualitative (QSA) and quantitative (QDA) data analyses; and the Strategic Flexibility Analysis (SFA) – a scenario analysis method which is the main focus of this paper. All the analyses ultimately culminated in development of a generic systems model. "Scenario construction has been applied to the development of emerging technologies and socio-technical systems, including initial applications to nanotechnology" (Wiek, Gasser & Siegrist, 2009, p. 285), however, this study is the first to apply SFA to skill identification for any emerging technology. The use of QSA in this study is very relevant since skill needs identification for an emerging socio-technical system like agrifood nanotechnology is so complex that the analytical basis does not allow for only quantitative modeling (Wiek et al., 2008).

4. Qualitative systems analysis (QSA)

A qualitative systems analysis was done in line with the theoretical underpinnings of this study (i.e., systems theory and complexity theory). The QSA included two main steps: (i) identification and selection of system variables and (ii) qualitative analysis of the mutual interactions among the variables - an impact analysis (Wiek et al., 2008). In this study four categories of system variables were identified from the qualitative data from the Systematic Review and the Multicriteria Value Elicitation using thematic coding. This follows the framework used by Wiek et al. (2008). The strengths of the impact on skill were subjectively evaluated using an ordinal scale from 0 to 2, where 0 means no impact, 1 a weak impact, and 2 a strong impact. This three-digit scale was appropriate for distinguishing between strengths based on the quantitative and qualitative data from the expert elicitation. A similar three digit scale has been used in previous studies (Wiek et al., 2008).

4.1. Focus variables (FV)

This set of variables includes the functional typologies of currently emerging nanotechnology applications in the agrifood system obtained from the literature and expert elicitation, which represent the starting point of the analysis. Determining a functional typology of agrifood nanotechnology applications helped to aggregate specific applications with similar characteristics into general skill requirements bracket (Wiek et al., 2008). Table 1 shows the final focus variables.

4.2. Context variables (CV)

As shown in Table 2, this set of variables is defined by the relevant factors influencing the development of agrifood nanotechnology applications with direct impact on future skill requirements. These variables include both historical antecedents and anticipated skill needs.

4.3. Target variables (TV)

This set of variables, as shown in Table 3, consists of the relevant occupational profiles in the agrifood systems that are or might be impacted directly by nanotechnology applications and thus direct nanoskill needs. Due to long list of occupational profiles within the agrifood cluster, we used the ONET categorization of occupational profiles into broad career pathways as the variables. According to ONET "Career Clusters contain occupations in the same field of work that require similar skills and thus students, parents, and educators can use Career Clusters to help focus education plans towards obtaining the necessary knowledge, competencies, and training for success in a particular career pathway"(ONET, 2013).

4.4. Action variables (AV)

This set of system variables consists of programs and policies in place to address nanoskill needs by industries (see Table 4). This set of variables is defined by the best strategy agrifood companies could use to address potential skill shortages and skill gaps that result from developments in Nanotechnology.

4.5. Impact analysis

An impact analysis was done to subjectively estimate the direct impacts of each variable on agrifood skill requirements, and also each variable on the others using Vensim™ Systems Dynamics Software for Windows. Each link contains information about the strength and quality of the impact between two variables. As mentioned earlier, the strengths were subjectively evaluated using an ordinal scale from 0 to 2, where 0 means no impact, 1 a weak impact, and 2 a strong impact.

To get a complete understanding of a system, it is important to describe and analyze the variables of the component parts and actors, as well as the linkages and interactions among these components that produce variable outcomes (Ericksen, 2008). This is the reason for introducing.

Impact Analysis as part of the overall QSA in this study. The explanation of the patterns and nature of linkages and interactions among the activities, external drivers, and the outcomes should therefore be the primary goal of describing the agrifood system in relation to future skill needs. This will help to assess any emergent properties, as well as cause and effect. Thus, while there is the inherent complexity of nanotechnology application in the food systems, a systemic approach to it analysis can reveal critical processes and factors that will determine the skills and competencies needed. It is important, however, that an adequate treatment is given to cross-scale interactions to prevent the analysis from failing to achieve the desire outcome (Ericksen, 2008). It is therefore, necessary to treat the nanotechnology application in the agrifood systems as multi-scale and level, even though the outcomes of interest may be focused on one particular scale; as in the case of this study where the focus is on the future skill needs in agrifood nanotechnology.

The strengths of Focus, Context, and Target variables were subjectively determined based on qualitative expert elicitation. The strength of impact of the Action Variables were obtained using quantitative elicitation data. In the case of the Target Variables the impact was determined for the career pathway as a whole and not the skills required. The impact analysis helps to understand the systemic particularities of functionally different nanoskill requirements. Fig. 3 depicts the causal-

Table 1
Description of focus variables.

Code	Variable	Nanotechnology	Function	Impact on skill
FV1	Nanostructured (also termed nanotextured) food ingredients	Processed nano-structures in food	Novel or improved tastes, flavors, textures	2
FV2	Nanodelivery systems for nutrients and supplements	Nano-encapsulated bioactive substances in the form of nanomicelles, liposomes or biopolymer-based carrier systems – mainly additives and supplements for food and beverage products.	The nanocarrier systems are used for taste masking of ingredients and additives such as fish oils, and protection from degradation during processing. They are also claimed for improved bioavailability of nutrients/supplements, antimicrobial activity, improved optical appearance, and other health benefits.	2
FV3	Organic nanosized additives for food, health food supplements, and animal feed applications	Organic additives (many of them naturally occurring substances) manufactured in the nanosize range.	Due to larger surface area, lower amounts would be needed for a function, or a taste attribute.	2
FV4	Inorganic nanosized additives for food, health food supplements, and feed applications	Inorganic additives manufactured in the nanosize range	Due to larger surface area, lower amounts would be needed for a function, or taste attribute. Other projected benefits include antimicrobial activity etc.	2
FV5	Food packaging applications	Plastic polymers containing (or coated with) engineered nanomaterials for improved mechanical or functional properties.	Improved mechanical and functional properties of polymers used as food contact materials or in food packaging.	2
FV6	Nanocoatings on food contact surfaces	Nanoscale coating.	Nanocoatings for FCMs with barrier or antimicrobial properties.	2
FV7	Surface functionalized nanomaterials	The 2nd generation nanomaterials that add certain functionality to the matrix, such as antimicrobial activity, or a preservative action, such as through absorption of oxygen.	For food packaging materials, functionalized ENMs are used to bind with the polymer matrix to offer mechanical strength or a barrier against movement of gases or volatile components (such as flavors) or moisture.	2
FV8	Nanofiltration	Filtration products based on porous silica, regenerated cellulose membranes.	Filtration of undesired components in food – such as bitter taste in some plant extracts. Also clarifying wines and beers.	2
FV9	Nanosized agrochemicals	Nanosized fertilizers, pesticides, veterinary drugs	Improved delivery of agrochemicals in the field, better efficacy of pesticides, and better control over dosing of veterinary products.	2
FV10	Nanosensors for food labeling	Incorporation of nanomaterials into intelligent inks (that respond to a change in the packaged food) to print labels that can indicate the safety and security of the packaged foodstuffs.	Sensors that can monitor condition of the food during transportation and storage.	2
FV11	Water decontamination	Nano-iron, other photocatalysts may also be used	Water treatment	2
FV12	Wireless nano-networks in agricultural fields, pesticide capsules	Nanotechnology applications that improve the agricultural output per area or/and time or/and input	Increase of agricultural efficiency	2

Note: The listing of these variables were adapted from FAO expert group report on nanotechnology as was recommended by experts through the qualitative elicitation.

functional framework of system variables corresponding to the stages of developments in agrifood nanotechnology and resultant skill needs (system analysis, future projection/scenario construction, impact assessment, strategy building), and possible causal relations between the variables.

5. Strategic flexibility analysis

As discussed earlier, SFA is a four-step framework, defined by Michael Raynor in his book *The Strategy Paradox*: *Why Committing to Success Leads to Failure (and what to do about it)*. The relevance and

Table 2
Description of context variables (CV).

Code	Variable	Description	Impact on skill
CV1	Development potential	Global know-how and infrastructure for R&D of nanotechnology.	2
CV2	Public awareness	Public awareness of agrifood nanotechnology, including basic understanding, perception of risks/benefits, and acceptance.	1
CV3	Consumer acceptance and demand	Consumer acceptance, demand and choices of agrifood nanotechnology, including habits, preferences, and values.	1
CV4	Laws and regulations	The legal framework for the development and use of nanotechnology, including laws, policies, executive instruments, and self-regulations.	2
CV5	Public investment	The amount of public resources allocated to R&D in agrifood nanotechnology.	2
CV6	Profit potential	The assumed business potential of nanotechnology applications, indicated by the worldwide private financial investments in nanotechnology.	1
CV7	Academia-government-Industry collaboration	Linkages between government, academia and industry to enable collaboration as a means through which one can address complex issues associated with agrifood nanotechnology.	2
CV8	Risk assessment	The available results provided by independent risk assessments on agrifood nanotechnology.	2
CV9	Public participation	The official involvement of society in scientific, governmental and industrial decision processes on agrifood nanotechnology.	1
CV10	Educational policy & curriculum development	Policies and a series of courses that help learners achieve specific academic or occupational goals in agrifood nanotechnology	2

Table 3
Target variables (TV).

Code	Variable	Occupational profiles	Impact on career pathway
TV1	Agribusiness systems	ONET categorization of occupational profiles and various career pathways	1
TV2	Animal systems		2
TV3	Environmental service systems		2
TV4	Food products and processing systems		2
TV5	Natural resources systems		2
TV6	Plant systems		2
TV7	Power, structural and technical systems		1

justification of the use of SFF as part of the overall study is to identify as quickly as possible the agrifood nanoskill needs that are unambiguous, while maintaining as much flexibility as possible in describing skills that are unclear due to the emerging nature of nanotechnology. The implementation steps are Anticipation, Accumulation, Formulation, and Operation as we have described earlier. In this study, the analysis was adapted and drawn substantially from the analytical approach developed by Deloitte LLC and described and used by Malik et al. (2009a,b). However, while Malik et al. (2009a,b) used it for anticipated investment portfolios in emerging technologies, in this study we used it for anticipated skill needs and the educational policy and programmatic interventions.

We started the process by defining the drivers that are shaping the agrifood nanoskill needs as obtained from a multicriteria value elicitation and also from the Systematic Evidence Review we conducted in the earlier phases of the overall multiphase study. These drivers of change are what we have already described as context variables for the impact analysis (See Table 2). Once we described these drivers, we developed scenarios that provide “stories” about possible future realities (Malik et al., 2009a,b) based mostly on the qualitative expert elicitation. The next step was the creation of optimal strategies for each scenario based on experts' opinions. We also identified the educational policies and programs needed to attain a given scenario. Different programs and interventions were then categorized as either core or contingent.

Subsequent steps of the SFA which were not included in this study due to limitations of time and scope, includes comparative analyses of educational policy reforms & interventions on the current trajectory with those chosen for each optimal strategy; detailed definitions of each optimal strategy along with descriptions of the types of risk associated with each educational policy reform & intervention; launching educational policy reform & intervention analyses; and, the construction of educational policy reforms & interventions portfolio.

Table 4
Action variables (AV).

Code	Variable	Impact on skill
AV1	Increase wages	0
AV2	Further automation and mechanization to substitute labor	0
AV3	Try to postpone retirement older employees	0
AV4	Recruiting workers from other sectors, or other countries	0
AV5	Recruiting young people from the education system	2
AV6	Use of specialized agencies/temporary workers/headhunters	0
AV7	Restructuring the (work) organization	0
AV8	Increase internal job mobility in the company	0
AV9	Outsourcing and off shoring	0
AV10	On the job training	1
AV11	Participation of employees in off the job training and education programs	1
AV12	Stronger cooperation with other organizations (trade unions, sector organizations and/or research institutes)	1

5.1. Scenarios

Four scenarios were developed based on experts and stakeholder responses to key qualitative elicitations questions. These scenarios are statements of how nanotechnology could shape the entire agrifood system and the logical consequence for new skills requirements. Each scenario attempted to identify the extreme limits of one of the drivers. This step is important because the insights gained by the process provides guidance to Human Resources Development and Management professionals to define the degree of flexibility in designing the necessary educational programs for agrifood nanotechnology workforce development.

Fig. 4 is the graphical depiction of the scenario construction and the interrelationships. It also gives an indication that the scenarios developed in this study are not exhaustive and several other scenarios can be created. Drivers of change are defined to fully capture uncertainty along several dimensions (Malik et al., 2009a) as shown in the diagrammatic representation.

5.1.1. Scenario 1: the world of Omics, Ology et al. — rapid nanotechnology innovation dominates

This scenario is shaped by rapid nanotechnology breakthroughs and innovations in agrifood systems, along with significant product development that will have direct impact on skills needs and workforce development. Some of the products and applications expected to affect the agrifood industry in this scenario include all the typologies described as Focus Variables under the QSA (See Table 1).

> Food and agricultural workers will increasingly be exposed to nanotechnology and thus, new management practices, and development and production distributed over multiple countries and carried out by people from multiple cultures. Such new work circumstances call for skills not traditionally taught in school: communications, working in teams, problem-solving, and so on. An Expert's Opinion

From this expert's opinion, while agrifood and food companies already are highly distributed over multiple countries this will see an enormous expansion as nanotechnology advances are specialized across different countries.

Economic and food consumption growth rates, along with population growth in emerging economies spur demand for agrifood products (Malik et al., 2009b). This creates a need for agrifood nanotechnology innovations and products. This need is complemented by demographic changes. The graying of the population in industrialized economies reduces the number of professionals involved in farming and animal production. Urbanization and industrialization in emerging economies reduce the human resources allocated to farming and production. These demographic trends fuel demand for increasing production efficiencies through nanotechnology innovations and for innovative agrifood products and thus the need for nanoskilled workforce.

> The future of agrifood nanotechnology depends in large part on the development of an efficient and productive research and innovation infrastructure based on interdisciplinarity. It requires as an input collaborative research from several fields of sciences such as: biological

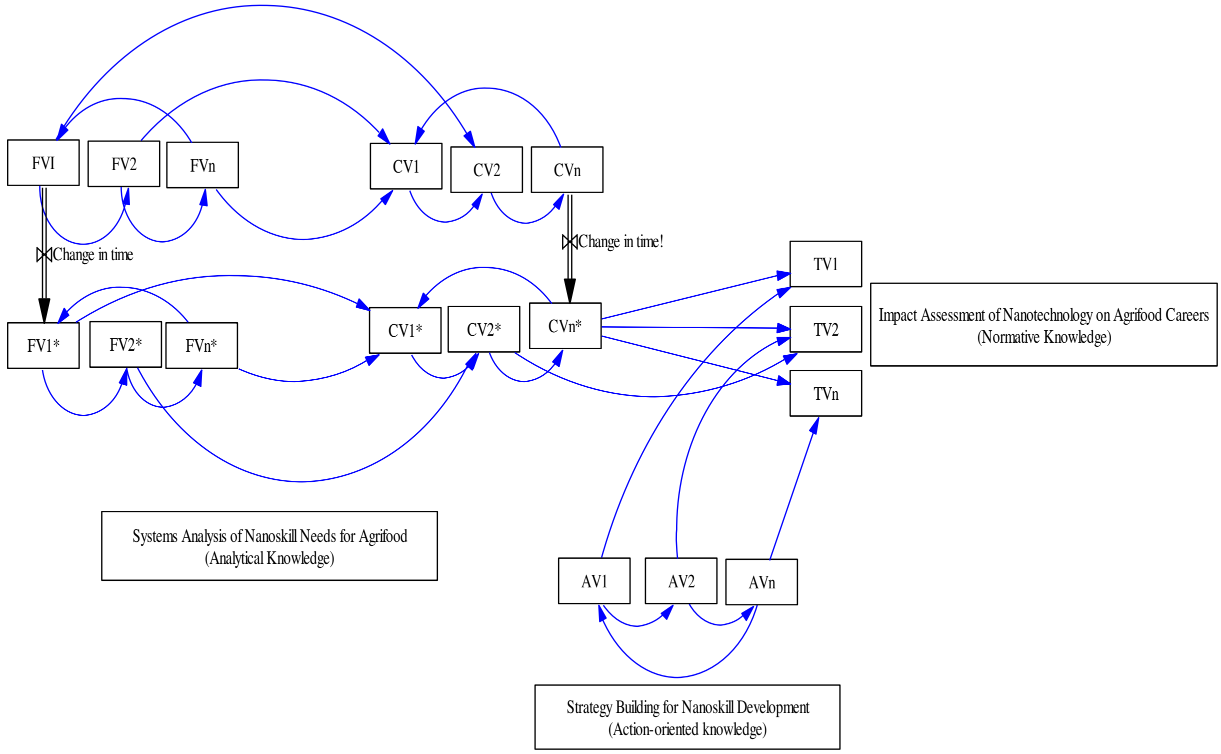
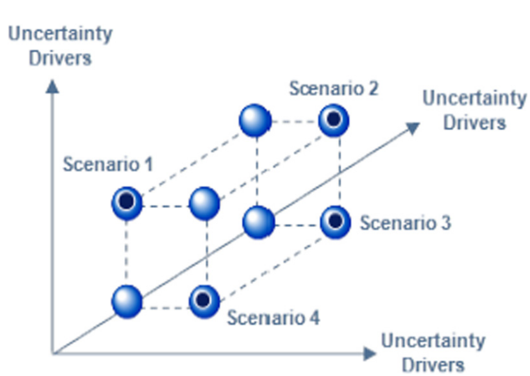


Fig. 3. Causal-functional framework of system variables.
Notes: The framework for this causal-functional analysis was adapted from Wiek et al. (2008). FV = focus variables, CV = context variables; FV* = future projections of focus variables, CV* = future projections of context variables; TV = target variables; AV = action variables.

sciences, physics, chemistry, electronic, engineering, mathematics, environmental and safety related disciplines, cognitive sciences, social sciences, etc. An Expert's Opinion

Consumer preferences also dominate this scenario. As it was and it is still with Genetically Modified Foods, so it is with nanoengineered foods (nanofoods). This scenario describes the contrasting issues that impact consumer acceptance of agrifood nanotechnology products and thus its successful commercialization. Generally, consumers associate more risks with novel food technologies than how they perceive risks of traditional food technologies (Siegrist, 2008). However, consumer acceptance of agrifood nanotechnology is strongly influenced by proponents and anti-proponent debates. Yawson and Kuzma (2010) concluded that consumer acceptance of agrifood nanotechnology is dynamic and varies depending on which effect is dominated between the several



Notes: Adapted from M. R. Malik et al., (2009)

Fig. 4. Creating scenarios.
Notes: Adapted from Malik et al. (2009a,b).

factors with perceived risks and benefit being the main dominant factors with all things being equal. Proponents of nanofoods, mostly scientists and policy makers, who based on scientific study, proclaim the importance of nanotechnology and how advances in its application can end hunger. The proponents assert that the vast majority of the research on nanofoods suggests that they are safe to eat and that they have the potential to feed millions of people worldwide who currently go hungry. At the opposite end of the spectrum are the skeptics and anti-nanofoods advocates who portray the advances of nanotechnology in food and agriculture as tinkering with nature with dire consequences.

> "An important component of responsible development is the consideration of the ethical, legal, and societal implications of nanotechnology. How nanotechnology research and applications are introduced into society; how transparent decisions are; how sensitive and responsive policies are to the needs and perceptions of the full range of stakeholders; and how ethical, legal, and social issues are addressed will determine public trust and the future of innovation driven by nanotechnology." (NNI, 2016)

5.1.2. Scenario 2: Rifkin meets Bridges on the future of work in agrifood nanotechnology

Continuous announcements of nanotechnology developments give an indication of the future of work in the agrifood industry. Developments in nanotechnology are likely to revolutionize the agrifood industry. "The impact of such research and development upon skills development for employability—both in-school and at the workplace—is likely to be phenomenal" (Maclean and Ordonez, 2007, p. 126).

There is no shortage of descriptions of the future of work in the literature, however, in this scenario, we focused on two very opposing future scenarios: Jeremy Rifkin (1994) *The End of Work* and William

Bridges (1995) *JobShift*. These opposing viewpoints each have substantial repercussions for the future of agrifood nanotechnology workforce. This scenario is driven by marrying Rifkinian view that any hope that the high-technology *knowledge sector* will create as many new jobs as are destroyed is futile, with Bridges' view that technology rather than eliminating job opportunities, will re-locate them. By marrying these two conflicting scenarios technology evolves as common driving force. On a spectrum, either nanotechnology will create new jobs and transform existing work to higher skill levels, or nanotechnology will destroy jobs or degrade them into less skilled, more routine work (Maclean and Ordonez, 2007). Experts were conflicted on this scenario. Most were of the opinion that, nanotechnology is already creating jobs and cite the United States National Science Foundation nanotechnology job creation report to support their opinion. The U.S. National Science Foundation (NSF) predicted in the year 2003 that 2 million workers will be needed to support the growth in nanotechnology by 2015 (Roco and Bainbridge, 2003). Several studies have also predicted a surge in workforce demand to an estimated 20 million by 2020 (Cleary, 2009; Hullmann, 2006; Roco, 2003). Other, experts were of the view that, just as automation and robotics have led to the decline of manufacturing jobs, nanotechnology will end work as we know it.

5.1.3. Scenario 3: the world is one flat world — a system of connected subsystems

This scenario describes the world as one system and it is predicated on Thomas Friedman's explanation of how the flattening of the world happened at the dawn of the twenty-first century (Friedman, 2005). Worldwide, trade, natural resources, and talent are each composed of interdependent sub-systems and the world is interconnected and complex networks of sub-systems that have both unique and common features (Malik et al., 2009a). One prediction in this scenario is that as agrifood nanotechnology companies continue to become more global, the R&D function will gradually spread throughout the world (Yawson, 2011). Teams will function through electronic networks and management of the R&D function could be directed from remote locations, and therefore, how do you prepare the workforce to be localized global citizens? What skills are needed?

> Because of ICT, nanotechnology, globalization, and other competitive forces, have all combine to alter how work gets done. We are now a more “flatter” organization with less hierarchy and lighter supervision where workers experience greater autonomy and personal responsibility for the work they do than just a decade ago. Work also has become much more collaborative, with self-managing work teams increasingly responsible for tackling major projects. An Industry Expert's Opinion

Globally negotiated ranges of policies, standards, and regulations will govern the production, trade, health and safety, and environmental sustainability of agrifood nanoproducts and this will have direct implications on nanoskills requirements. Moreover, as nanotechnology becomes even more powerful driver globally, and national environmental challenges and regulations diminish in relative weight, skills needs will become increasingly even across countries and nanoskills will become less country-specific than they are at present (Strietska-Ilina et al., 2011). This means that changes in demand for, and in the content of, skills in the agrifood sector in other countries can inform policy decisions and training responses in here in the United States. There will thus be a need for more information on core, changing and emerging occupations and their skills content at a global level (Strietska-Ilina et al., 2011).

Nanotechnology is multidisciplinary, interdisciplinary, and transdisciplinary field and thus will boost the call for the convergence approach in relation to skill needs and workforce development. The convergence perspective is a new approach to promoting trans-, inter-, and multidisciplinary research and the development of technology that can be used in various fields.

5.1.4. Scenario 4: the education pipeline leaks — there are precedents and antecedents

There is no doubt that the United States leads the world in scientific and technological innovations and probably not among the best in K-12 STEM education in the leading industrialized countries (Goodstein, 1993). There is very little debate that both of these apparently contradictory assertions are true. Scientists, trained in United States graduate schools produced more Nobel Prizes, more scientific citations, more of just about anything you care to measure than any other country in the world; possibly more than the rest of the world combined (Goodstein, 1993). Consistently, the National Center for Education Statistics, for example, has found that educational attainment (as measured by upper secondary and university completion) in the United States as the highest among all G-8 nations. Yet, students in U.S. lower secondary and below consistently rank at the bottom of all those from the leading advanced nations in tests of scientific knowledge (Goodstein, 1993). However:

> A key challenge for nanotechnology development is the education and training of a new generation of skilled workers in the multidisciplinary perspectives necessary for rapid progress of the new technology. …Such education and training must be introduced at all levels, from kindergarten to continuing education, from scientists to nontechnical audiences that may decide the use of technology and its funding. (Roco, 2002, pp. 490 -491)

This scenario is therefore, based on the logical consequences of the paradox described. Due to the excellent nature of United States higher education system and the focus on advances and innovation in nanotechnology at that level, with the apparent neglect of Career and Technical Education (CTE) and also the continuous poor showing in STEM education at K-12 level, a future skill gap may be created. The United States will continue to lead the world with innovations but all the manufacturing and the related applications will be done elsewhere. There is a precedent and antecedent to this: The shipping of IT jobs overseas can be attributed to several reasons, but one key reason is that the middle level technical workforce are not available as compared to India and China.

> CTE should be a main part of any nanotechnology driven educational reform. However, if CTE is to have a role in successfully preparing agrifood nanotechnology workforce, a look at program content, how to deliver CTE programs, and let go of what no longer works. The dichotomous silos of academics versus CTE must be eliminated and their supporting infrastructures must be re-imagined to meet the needs of the economy. As result of blurring of disciplines with the emergence of nanotechnology, so too must the lines that currently separate GE and academic education. An Industry Expert's Opinion

There is therefore the need to seal all the leaks in the educational pipeline and CTE should be a main part of any nanotechnology driven educational reform. However, we must add that not all experts agreed to the role of CTE in our interviews. “Technology development should be done in 4 year Universities rather than vocational venues because the technology requires expansive skills development only acquired in 4 year school and graduate work”. An Academia Expert's Opinion

5.2. Choosing strategies

Choosing strategies representing the full range of strategic uncertainty relevant to the agrifood industry were obtained from the Systematic Evidence Reviews (SER). These were then formulated into questions as part of the expert elicitation.

5.3. Identifying optimal strategies

Identifying optimal strategies relevant to the agrifood industry were obtained by responses of experts to several elicitation questions including: consumer acceptance of agrifood nanotechnology, the best strategy agrifood companies could use to address potential skill shortages and skill gaps that result from developments in nanotechnology; measure(s) agrifood businesses should take now to address skill needs; what should be improved within the higher education system to better fulfil skill needs related to developments in nanotechnology; and, what should be improved within the vocational education and training/Career and Technical Education system to better fulfil skill needs related to developments in nanotechnology.

Fig. 5 shows graphical representation of identifying the optimal strategies and educational policy reforms and interventions. Optimal strategies to address issues of the various scenarios based on current situation provides the core and contingent approaches to the educational policy reforms and interventions needed to prevent any future skill gaps in agrifood nanotechnology.

In determining the optimal strategies for the various scenarios, experts' opinions were sought on the best strategy agrifood companies could use to address potential skill shortages and skill gaps that result from developments in nanotechnology, and 44% of experts indicated that recruiting young people from the education system was the way to go. Seventeen percent of experts indicated that stronger cooperation with other organizations (trade unions, sector organizations and/or research institutes). Another 17% were of opinion that participation of employees in off the job training and education programs could be used to address potential skill shortages and skill gaps that result from developments in Nanotechnology

Experts were also asked to indicate measures agrifood businesses should take now to address skill needs, and 57% stated that working with the local educational institutions to provide training and recruiting. Nineteen percent said conducting skills inventory; 14% said predicting future skills inventory; and, 10% with the opinion that developing in-house skills training/mentoring. Experts were then asked whether they think the higher education system (universities, polytechnics, higher vocational education) in the United States can fulfil skill needs related to present and future developments in nanotechnology and 65% said to a great extent, with 18% indicating somewhat, 13% saying somewhat.

On what should be improved within the higher education system to better fulfil skill needs related to developments in nanotechnology, experts indicated several opinions with 70% indicating stronger cooperation with companies, and 55% indicating the need for more opportunities for training courses for experienced professionals to update skills and acquire new skills. Fifty percent were also of the opinion that new types of higher level science courses should be started, and 35 indicating that there should be less specialization within science, but more general knowledge of scientific domains within science.

Experts were also asked to indicate whether the vocational education and training (VET)/Career and Technical Education (CTE) system in the United States can fulfil skill needs related to present and future developments in Nanotechnology. Thirty-nine percent selected "somewhat"; 17% said to a great extent and another 17% saying very little. Twenty-two percent expressed no opinion. Experts were further asked to indicate, if relevant, what should be improved within the VET/CTE system to fulfil better skill needs related to developments in nanotechnology. The following results were obtained: Sixty-two percent indicated stronger cooperation with companies; 52% selected more opportunities for training courses for experienced professionals to update skills and acquire new skills; 43% indicated a start of new types of vocational specializations in the education system; 38% indicated the need to improve conditions for companies to employ apprentices and interns from the vocational education system; and 33% selecting increasing the supply of graduates, especially in relevant fields.

Experts' opinion was sought regarding the government's role in development of nanotechnology, and 43% indicated that government should co-invest in industry-led nanotechnology developments, 33% were of the opinion that government should co-invest heavily and offer strong incentives to industry; and 24% indicated that industry takes the initiative, and government oversees the nanotech industry. Results of the stakeholder surveys were also presented similarly like that of the Experts, but are not shown in this paper due to space considerations.

Public engagement is important if the critical issues of consumer acceptance of agrifood nanotechnology are to be effectively addressed. The public should be seen both as unambiguous stakeholders interested in agrifood nanotechnology and the larger public, being citizens and consumers.

6. Conclusion

The strategic flexibility analysis of the results of this study bring out the important policies and programmatic intervention points that can serve as leverage points for increasing the likelihood of preventing skill gaps and shortages in the agrifood sector. The broad scheme for dynamism of systems and the results of this study would perhaps provide some leads and ideas for future study to fill data gaps. Although the goal of the SFA was not the accurate quantitative estimation of forecasting

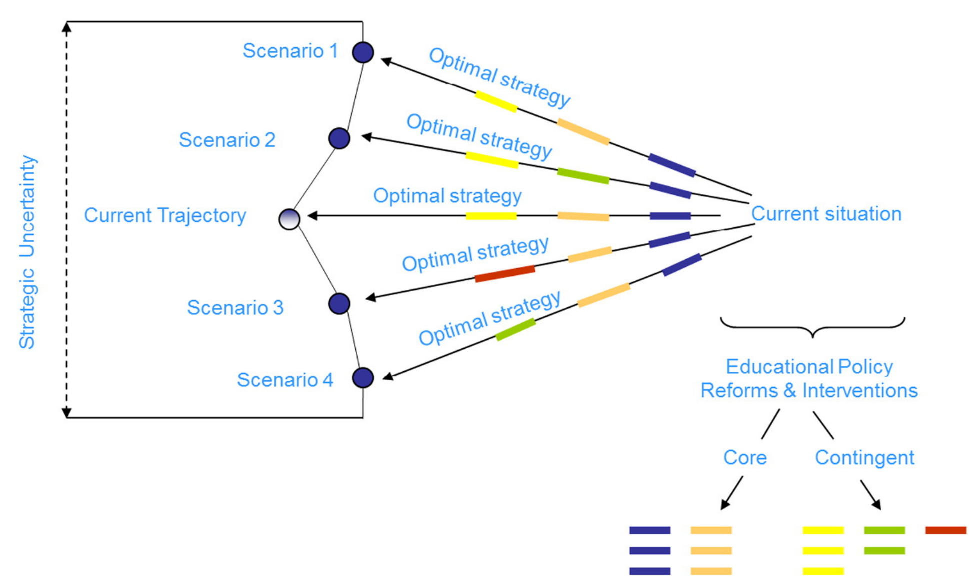


Fig. 5. Graphical representation of identifying the optimal strategies.

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for future skill needs in agrifood nanotechnology, it enhances the understanding of the mechanism of skill needs identification in agrifood nanotechnology as a system. The SFA can be adapted to suit several purposes including curriculum development, educational policy formulation, skill needs identification and related issues to properly understand the interrelationships and what may be unintended consequences of policy implementation.

Interdisciplinarity of nanotechnology was a recurring issue in the multicriteria value elicitation and the SER. It is our contention that interdisciplinarity in the context of nanotechnology is more than knowledge exchange between different well-defined disciplines; instead, disciplinary boundaries should be constantly redrawn and renegotiated during the process of exchange based on various stakeholder interests. However, skills should not be seen as mere servant of the economy, solely reactive in the face of change. “Every policy can tap the power of skills to promote change, if skills are considered an important function of the planning and implementation processes” (Strietska-Ilina et al., 2011. p. 162). Framing interdisciplinary skills in nanotechnology as a sociopolitical boundary-making process may clarify training issues in Nanoeducation (Tsai-hsuan Ku, 2012). Stakeholder interest in describing nanotechnology as interdisciplinary and the ensuing requirement for the acquisition of interdisciplinary skills can be daunting. Some of the industry/business experts interviewed for example framed this problem as one of ‘a shortage of nanoskilled workforce’, but the process of developing interdisciplinary nanoskilled employees have been proven to require “carefully designed organizations to establish a disciplinary order capable of focusing resources, knowledge, and labor to bear on specific problems without being diverted by diverse interests” (Tsai-hsuan Ku, 2012, p. 376).

Several recommendations can be gleaned from the findings of this study and the following are some of the key programmatic intervention points that serve as our recommendations:

- Agricultural educators and human resource development professionals in the agrifood system risk arbitrarily narrowing their options of meeting the challenge of developing the human resources equipped with the requisite agrifood nanoskills if they attempt to base how the workforce should be developed on a precisely predicted skill requirements alone. This could prevent the consideration of a broader range of future possibilities. Agricultural educators and HRD professionals need a range of future possibilities and corresponding strategy choices in tailoring their activities, rather than one strategy based on a declared vision of certain future skill requirements. The strategic flexibility analysis done in this steady can serve as an important primer for addressing these broad range of future possibilities.
- Increased engagement between all stakeholders in the agrifood sector especially Government, Technical/Community colleges, Universities and Business/Industry in relation to the content, design and delivery of educational program (so curriculum and training throughout the workforce development pipeline can adequately meets the needs of the sector).
- Employers will hire qualified students wherever they are. If agricultural educators fail to align their curriculum with the skill needs of agrifood industries in the wake of the emergence of nanotechnology, companies that traditionally employ graduates from colleges of food and agriculture may look elsewhere in the universities and colleges and may find better qualified students in other colleges throughout the university as a result of the trans, inter and multidisciplinary nature of nanotechnology. Due cognizance should be given to changing the foundation of learning in colleges of food and agriculture, beginning with broader concepts of nature, and converging platforms in the freshman year, instead of beginning with introductions to narrow disciplines (Roco et al., 2013).
- “Any curricula developed for agrifood nanotechnology should be based on good theoretical foundations and a balance of knowledge competencies drawn from mathematics and the physical sciences together with the chemical and biological sciences integrated with applied sciences, commerce, management, social sciences and the humanities”. (Yawson, 2010, p 290)
- It is important that industry play an active role in the provision of leadership to address agrifood nanotechnology workforce and skills development related issues, most importantly by working closely with academia and government stakeholders to develop and drive the implementation of unified and enduring solutions to agrifood nanotechnology workforce and skills needs.
- Nanotechnology should be incorporated into all aspects of K-12 STEM education programs and initiatives. From systems perspective, STEM education should not be devoid of the employability skills, or else there may be the unintended consequences of highly trained future STEM workforce with no employability skills.
- It is important to implement an initiative to identify existing public and private initiatives in each State that focus on addressing workforce development, skills development, education and training issues in nanotechnology so as to identify best practices and also linkages or inconsistencies between existing initiatives to improve stakeholder awareness and understanding of, and accessibility to existing measures. This will help in sharing knowledge and learnings and best practice approaches to identify gaps and opportunities for future work or new initiatives and improve coordination and consultation between States in the implementation of agrifood nanotechnology workforce development programs.

The focus of this paper has been the use of the Strategic Flexibility Framework for Strategic Flexibility Analysis as part of a whole systems approach methodology. It is our contention that, although, it can be used as a standalone methodology, in order to make the most effective contribution to human resources development and human capital predictions in this century of complexity, unprecedented interconnectivity, interdependence, radical innovation and transformation, and unforeseen new structures with unexpected new properties, it is important to go beyond using it as a single method to generally using multiple methods and combining several methodologies, in whole or in part, and possibly from different paradigms, and different disciplines as was done in the original study. However, to do that one would have to understand how each of these disparate methods fits in the overall scheme of the systems approach. It is our hope that this paper will therefore present a new look at how the future can be described from a systems perspective.

The strategic flexibility analysis of the future skill needs of agrifood nanotechnology, combined with the broad exploration of agrifood nanotechnology workforce development, is useful in several ways. Specifically, decision makers in academia, government, and industry, can match these findings with their strengths and develop a vision for agrifood nanotechnology workforce development initiatives. Based on our findings, and on the strategic flexibility analysis, decision makers can develop high-level recommendations to build industry's foundational capabilities through policy, infrastructure, and education initiatives.

Another application is a more constrained execution of the Strategic Flexibility Framework to determine educational and workforce development-specific strategies and to plan for the future. Specific entities can build on this analysis and create initiatives in corporate strategy that can reduce anticipated future skill gaps and growth as well as inform educational policy and programmatic intervention activities. For example, an industry decision maker can use the process to reconfigure an in-house strategic on-the-Job training and human resource development portfolio. Similarly, a university can use the framework to reconfigure its academic programs and more firmly determine which core curricula changes should be made and which contingent pedagogical innovations can create options if pursued partially or in partnership with other entities. Likewise, a state government can use the framework to create new agrifood nanotechnology workforce development initiatives, identifying core nanotechnologies that require investments for

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creating knowledge clusters in public universities or for building basic science concepts in K-12.

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